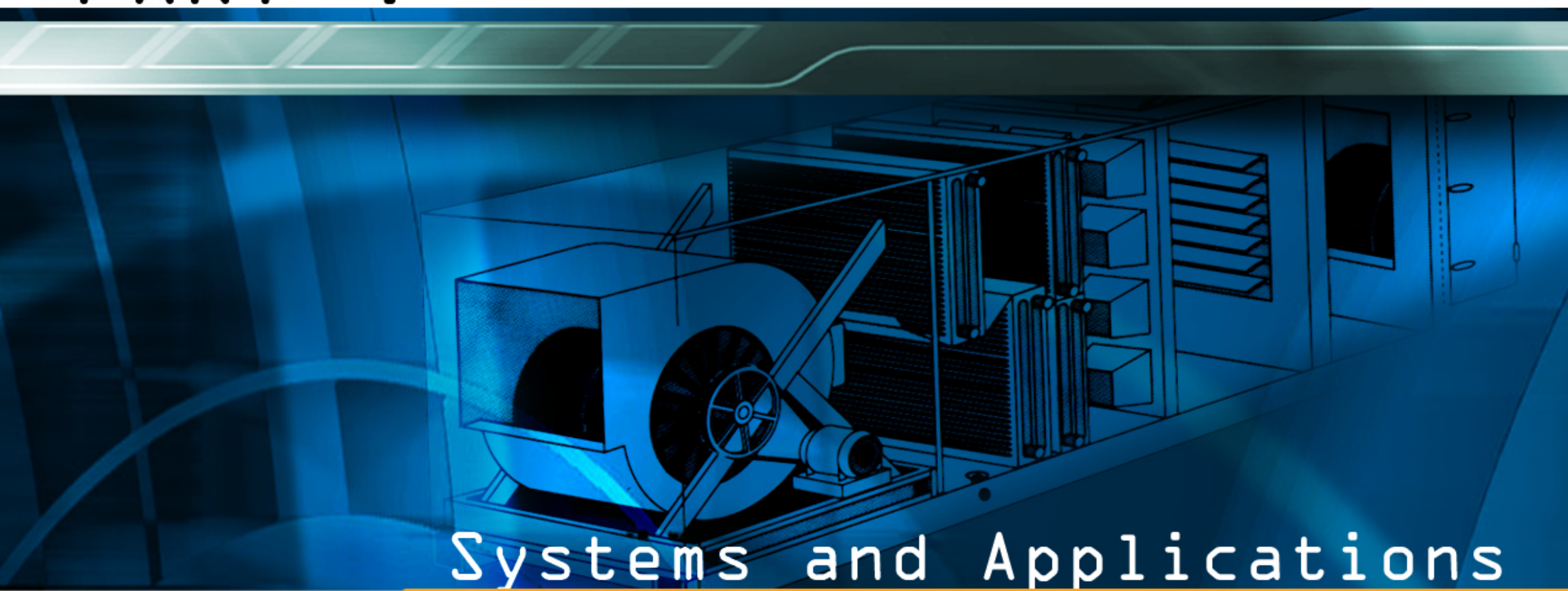
PART 9



Systems and Applications

CONTENTS PART 9 SYSTEM AND APPLICATIONS

SYSTEM DESIGN MANUAL

SUMMARY OF PART NINE

This part of the System Design Manual presents guides for selecting the air conditioning system used with specific applications.

CHAPTER 1. SYSTEMS AND APPLICATIONS

This text introduces the engineer to the preliminary considerations and project aspects for determining the selection of an air conditioning system. The part sketches the systems available and compares their performance and applicability to various spaces and buildings. It also indicates the particular problems of selected applications, stressing the important functions of air conditioning. It presents a broad review only; details of various systems and their design are presented in other parts of this manual.

SCOPE AND INTENT

Selection of the correct air conditioning system for a particular space or building is a very critical decision facing the design engineer. On this decision rests the satisfaction of the customer and occupant and the system fitness to the building it serves. Many factors must be analyzed, judged, screened and coordinated. The desires of the investor and the economic aspects are the foremost considerations.

CUSTOMER AND OBJECTIVE

There is a big gap between a customer who thinks in terms of simple relief cooling in a room or small establishment and the one who builds a monumental building representing the epitome of an integrated concept of a structure and the environment within, whether architectural, acoustical or air conditioning.

Complete air conditioning provides an environment of correct temperature, humidity, air movement, air cleanliness, ventilation and acoustical level. Anything less is a compromise and is not termed air conditioning. Therefore the particular system involved should be identified with the function which the system design is to accomplish, whether heating, cooling, humidity control or complete year-round air conditioning.

There must be complete fusion of system and building to lead to a natural and normal behavior as a whole in disposing of the heat gains or offsetting the heat losses.

ECONOMICS

These considerations affect the type of equipment and the whole system that is offered to the prospective owner. The economic factors are foremost. They originate from the owner's desire and capacity to invest in an installation that is intended to provide either a minimal or a maximum benefit. It must be determined whether the project is an investment for a quick write-off, a resale or a long term investment. The investor may seek either the lowest first cost, the lowest first cost in balance with the economical owning and operating costs, or strictly the lowest owning and operating costs. Above all the investor is interested in a profitable return on his investment.

PROBLEM

To realize a substantial advantage from an operation of air conditioning in a space or a complete building, the design engineer must consider fundamental situations. He must first define the problem. He must be able to anticipate the behavior of the contemplated air conditioning system. For given conditions of external environment and internal load, the system must integrate with the space or the building which it is to serve. The system must satisfy the maximum instantaneous or actual thermal load* and be operable at any partial load conditions.

The fundamental diagnosis should consider:

1. Investor's financial capacity and the investment objective.
2. Space or building
   a. Purpose
   b. Location
   c. Orientation and shape
3. Coincidental occurrence in external environment of
   a. Temperature
   b. Humidity
   c. Wind
   d. Exposure to sun or other heat exchanges
   e. Shade
4. Diversity of internal load
   a. Occupancy
   b. Lighting
   c. Other heat exchanges
5. Capability for storage of heat gains
6. Necessity and capacity for precooling
7. Physical aspects of space or building to accommodate
   a. Equipment
   b. System
   c. Balanced operation at partial load
8. Customer's concept of environment desired

*Thruout this discussion load shall mean the thermal load of heat gain or loss to or from a building and its content.

INTEGRATION

Each space or building presents an individual problem to resolve. There is no universal solution to a system selection even after it is defined, the physical circumstances evaluated, and the actual load of heating and cooling requirements established. The design engineer must have an appreciation of the structure, its thermal capacity behavior, and the response accorded it by the contemplated system. He must understand the interaction of space or building with external and internal thermal loads and the cancellation of these loads by the system. There should be a full realization that the equipment installed, the control of the air conditioning system, and the building are irrevocably integrated into one whole. To be successful these elements must be coordinated to operate as an entity.

The discussion that follows is a resume of factors that constitute the preliminary qualifications of a project. it offers a guide to the selection of a system best suited to a given circumstance surrounding an application. All types of systems are reviewed briefly, from a self-contained room unit to an elaborate central station system.

The range of systems applications for human comfort is covered from a residence to a high rise apartment building, from the smallest commercial application to a skyscraper or a factory.

SPACE AND BUILDING

OCCUPANCIES

The wide range of spaces and buildings for application of air conditioning for human comfort may be divided into two fields, single-purpose and multipurpose occupancies.

Single–Purpose Occupancies

Single-purpose occupancies involve either an individual or a multitude of individuals gathered for a common purpose of work, prayer, relaxation or amusement. The predominant characteristic is the presence of a single environmental control zone. Examples include a room, residence, or large open area with or without low partitions.

The large area may be an office space, restaurant, beauty salon, etc., at times set in an individual small building. The larger structure may be a church, theater, auditorium or pavilion. The common feature is a building with one or more large open spaces as a major area to be air conditioned.

Multi-Purpose Occupancies

Multi-purpose occupancies involve a multitude of people gathered for various purposes in one or more multi-room, multi-story buildings. These buildings may serve a single purpose: a sale of goods, department store; book lending or collection, a library; a collection of articles of special interest, museum; research, laboratory; learning, school; manufacturing, factory; etc. Generally the multi-room, multi-story buildings may be office buildings, hotels, apartment buildings or hospitals. To the multi-purpose occupancies also belong building compounds of apartment houses, schools, colleges, medical and shopping centers, and factories.

The major characteristic of these occupancies is a multiplicity of environmental control zones served by a single or multiple, preferably central, air conditioning system. With increases in size and number of central station units in a single system, sources of refrigeration and heating are consolidated into one or more large refrigeration and boiler plants.

THERMAL LOAD

When an engineer is faced with an existing space or building, little can be done to alter these structures to aid either the reduction of the air conditioning load or system accommodation unless a major alteration is embarked upon. Definite limiting circumstances may exist.

On the other hand a new building provides freedom and challenge to the architect-engineer team. They may devise a structure that is architecturally and acoustically acceptable and pleasing, at the same time one that incorporates all possible forethought to minimize the air conditioning load. Proper orientation in regard to exposures and analysis of shading (external or internal) is essential. *Space is required for air conditioning equipment and for transmission and distribution of heating-cooling effects.

Building Shell and Outdoors

A building or a space is a thermal container, an enclosure. Within it an air conditioning environment for human comfort is to be maintained, regardless of seasons and outdoor climatic conditions. The considerations involving the construction of a building shell are: thin panel vs massive wall and partial vs total glazing. Other considerations are: glass and wall shading, orientation of the building (simple or complex architecture), height and shape, predominance of peripheral or internal areas, and single zone vs multi-zone application.

*Sun gain thru 150 sq ft of unshaded west glass requires approximately one ton of cooling capacity as against only one tenth of a ton required for the glass with north exposure.

These considerations are pertinent to evaluating the external influences on the air conditioning load of simultaneous occurrence of temperature, humidity, wind and solar conditions. These constitute the outdoor design conditions.

Internal Elements

The selection of the inside design condition for space or building establishes the thermal head against which the air conditioning system will operate at any load condition. The internal load behavior is determined by the diversity factor that can be applied to the population, lights and any heat-pro-ducing or extracting equipment or situation. The smaller the space, the less the diversity; an air conditioning cycle applied to an individual space takes full account of instantaneous load. However, with an increase in the size of a project, the requirements for refrigeration capacity grow. A larger diversity factor may be applied. In most cases the possibility of application of either the heat storage principle or precooling effect should be considered in order to reduce the cooling-heating load (approach the actual load) or reduce the size of equipment.

Part 1 contains information on the evaluation of an air conditioning load. It must be re-emphasized that *an estimate of the actual cooling-heating load is the most fundamental step* before selecting an air conditioning system and equipment. This must be preceded by a thorough survey.

Partial Load

A necessary corollary to the evaluation of actual load is an appraisal of load behavior at partial conditions: possible variations in the internal load; effect of change in external weather elements; reaction of the thermal enclosure and barrier, the structure. The shell's thermal capacity and physical porosity may have great influence on the amplitude of the peaks and valleys in the daily load curves. The system picked for the particular situation must have certain flexibility. Thus the load, the enclosure and the air conditioning equipment in a complete system (total complex) regulates the space environment.

SPACE FOR EQUIPMENT AND SYSTEM

The air conditioning equipment and system auxiliaries require space. The industry is continually devising means and methods to reduce the size of the equipment, the elements of the total system, and their costs, yet produce the same total capacities of cooling and heating at a reasonable investment. Until some radically new approach is discovered, the present means to provide comfort require space.

Self-Contained Units

The extent of space requirements may be small enough to take care of a room unit or a self-contained apparatus within the air conditioned area. Both are types of miniaturized central station plants of small capacity. Such packages contain all the elements to provide complete air conditioning in one enclosure, yet convenient to handle as a unit. The spaces required affect directly the conditioned area; however there may be cases where the units are installed external to the conditioned space.

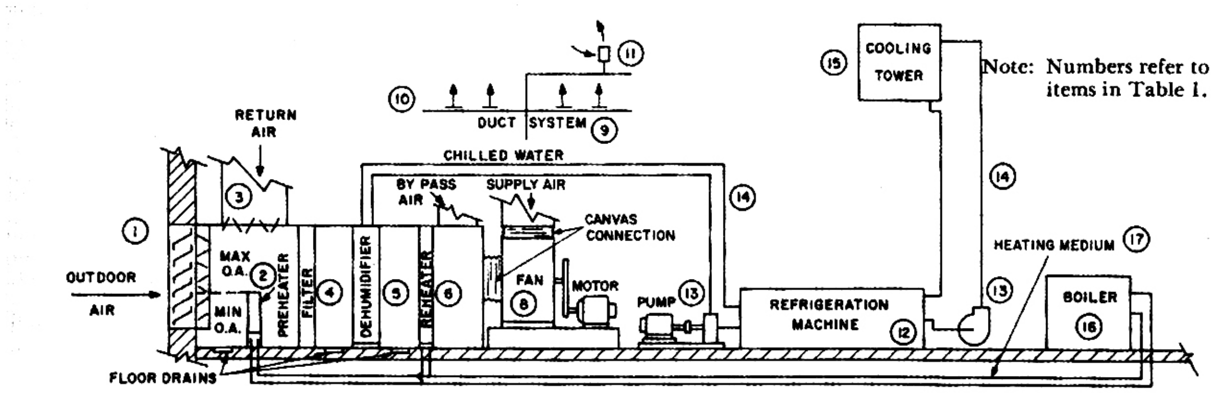


FIG. 1-AIR CONDITIONING PLANT

Central Stations

For a large central station system space has to be provided for conditioning, heating and refrigeration machinery. The cooling-heating media requires space to be transmitted to the conditioning apparatus and then to the areas to be conditioned. There are terminals within the conditioned areas for the final delivery of the cooling-heating effects.

Thus there is a conditioned air path from the out-door air intake thru the apparatus, thru ducts to terminals within the conditioned area; there are refrigeration and boiler plants and interconnecting piping to air handling apparatus and in some systems to terminals *(Fig. 1).* Except for within-the-room terminals the system space required is external to conditioned areas. At times areas that can be utilized more profitably may have to be surrendered for use by some elements of the system.

BASIS FOR DESIGN

The design engineer must make a correct appraisal of the building or space to be conditioned. He must define the problem. He must evaluate the characteristics of the space or building, the climatic environment and the internal heat gains or losses. The evaluation of maximum actual load, its behavior at partial conditions, and the thermal capacity of the enclosing structure are the elements and the foundation to guide the selection of the proper air conditioning system.

QUALIFYING SYSTEM SELECTION

ECONOMICS

Having pointed out the physical aspects and requirements of air conditioning of space and building, a review of the intangible aspects is necessary. These are the customer's concepts of (1) financial involvement and realization of income gain, (2) achievement of the environment of temperature, humidity, air cleanliness, air motion and quietness, (3) realization of flexibility of controls, and (4) insight into limitations of the structure. By clarification of these aspects proper judgment and mutual appreciation between the customer and architect-engineer team is accomplished.

Buyer

The air conditioning market is vast and very competitive. The ultimate user-buyer may be a shrewd investor looking for a quick turnover of capital or a customer who is satisfying a need to neutralize competition that surrounds him, or an owner creating the utmost in monumental progressive design and application.

There are three factors in the economics of system selection: (1) first cost, (2) operating and maintenance costs, and (3) return on an investment. The buyer may be looking for either extreme, the lowest first cost or the lowest operating cost. He may rely on the design engineer to arrive at a balanced proposal. He may desire a monument irrespective of any costs. The design engineer must weigh not only the engineering considerations but the customer's financial attitude and desire for return on the investment.

Investment

One aspect in the economics of selection of an air conditioning system is the actual longevity of equipment and auxiliary components, that is, the write-off life span permitted by the government for depreciation for tax purposes. The net effect is apparent in the analysis of owning and operating costs.

Owning Costs

The owning elements of costs is influenced by the price of the equipment, materials labor and services for an installation. These components must be weighed carefully in arriving at a selection of a system. With an existing building there is an additional element, the interference with regular business.

Operating Expense

Operating costs are influenced by the consumption of energy, whether electrical, steam, gas or other; this is the bulk of operating costs. There is also the item of maintenance consisting of the operating personnel and upkeep of equipment together with supplies of oil, filters and other materials. The equipment working condition is its condition approaching that of the original installation except for the normal duty wear.

The otherwise rentable space given up to accommodate the air conditioning system is also an element in operating costs.

Return on Investment

In the final analysis the rent or any income producing increment is of major interest to the investor. Investment analysis is a gauge for determining whether or not money spent on a proposed project will be wisely invested. It can be used to establish the merits of air conditioning as a sound investment compared with money invested in any other manner.

Investment analysis is the owning and operating cost analysis to determine on a unit basis the incremental cost due to the addition of air conditioning. To the prospective owner this cost is an added cost per square foot, per room, per apartment unit, per hospital bed, or per factory worker. This added cost is compared to the expected incremental income. Such a tally determines whether an investment in this or another system is profitable, and which system is more profitable than another.

Budget Analysis

During the preliminary budget stages approximations based on experienced judgment should be made to determine the thermal load and the cost of various systems. This procedure provides the basis and affects the results of the qualifying investment analysis. That air conditioning can offer attractive investment potential is easily established by a budget analysis. Since investment return varies with each system and with the length of elapsed time before the owner plans to liquidate the investment, two or more analyses must be made to determine which of several applicable systems is the best investment.

ENVIRONMENT

Temperature and Humidity

The foremost prerequisite of comfort air conditioning is temperature control and the regulation of humidity is of secondary importance. All systems have the facility of controlling the comfort range of temperature. The human tolerance of humidity variation is considerable.

Air Cleanliness

There are considerable variations in air cleaning requirements; they depend on the location of the particular project, the fastidiousness of the customer, and the costs of cleaning. The latter include the initial investment and maintenance costs. Odor and bacteria control may also be required; at times this is an absolute necessity. Air must be clean.

Air Movement

With any air conditioning application a system may have the required cooling-heating and cleaning capacity but, if the air is not properly distributed and not in effective motion, all the requisites of proper air conditioning are not fulfilled. Air movement depends on the amount of air in circulation and direction of air delivery; both are determined by the type of air distribution employed. Air movement definitely assists in the sensation and appreciation of comfort.

Acoustics

Part of the work produced by equipment and cooling-heating media in motion is always converted into sound energy. When reaching the conditioned areas, this energy may be a welcome masking which contributes a desirable amount of ambient noise, to make the space “quieter” by making it noisier. On the other hand it may be objectionable and annoying. The designer must evaluate the location of the equipment and system elements in relation to surrounding occupancies, the mass of the structure, the air conditioned space, and the location of the building (busy city or peaceful country). Then the designer must establish the desired sound level within the air conditioned space relative to the terminal or terminals in that space and the type of occupancy. This is part of the total comfort environment.

The achievement of this objective involves the cooperation of the customer and architect-engineer team. Proper design must be applied to the building, the distribution of spaces that are critical sound-wise, and to the location and soundproofing of various machinery and system elements. The team must be concerned with the evaluation of sound level within air conditioned spaces.

CONTROL REQUIREMENTS

Choice of an air conditioning equipment and system depends on the character, nature and behavior of the cooling-heating load under partial conditions.

Nature of Thermal Load

It is necessary to determine whether the load is mostly sensible or latent, highly concentrated or light, uniformly distributed or variable in a regular or haphazard pattern. All these factors are involved in a decision, one zone or a multi-zone system. These considerations are necessary for selecting an air conditioning system and its control which maintains the desired conditions under partial load. This means achievement of controlled conditions under broad or exacting requirements.

EXISTING VS. NEW STRUCTURES

There is a distinct difference between systems available for existing or new buildings. In existing enclosures or structures heating and at times ventilation is already supplied. Therefore the additional system is for cooling only, adapting and integrating the existing heating-ventilation into a year-round cycle. The air conditioning systems to be selected are limited to those operable from overhead and sometimes to systems that can be applied on an individual space-to-space or floor-to-floor progressive basis.

In new structures or in those where the existing heating systems are discarded, the exterior areas may be treated by complete year-round systems. In exterior areas there are air conditioning systems specifically designed for highly variable peripheral thermal loads, systems that have many different arrangements. For interior areas, depending on the type of arrangement, their use and thermal loads, there are also available a wide variety of systems.

Having determined the economic aspects of the project, that is, the profit realization by an investor, the extent of the requirements of environmental conditions, and their control, the engineer is ready to select the system.

SYSTEMS

A review of the fundamental evolvement of a variety of systems is presented here.

OBJECTIVE

The objective of an air conditioning system is to provide a comfortable environment for an occupant or occupants of a residential, public, medical, factory or office building. It may be for a number of transient occupants in a commercial establishment such as a store, a bowling alley, a beauty salon, a restaurant or others. It may be for an assembly of occupants gathered in a large space such as a church, theater, auditorium, pavilion, or a factory loft or floor.

The comfort environment is the result of simultaneous control of temperature, humidity, cleanliness and air distribution within the occupant's vicinity that includes the proper acoustic level.

The final media used to achieve a comfortable environment are air and surfaces surrounding the occupant. Both the air and surfaces of the enclosure are sinks for the metabolic heat evolved by the occupant (*Fig. 2*).

Air circulates around the occupant and the surfaces. The occupant also has radiant heat exchange with the surrounding surfaces. Air is brought into motion within a given space either thermally or by force.

Thermal air motion usually occurs over heating convectors within the space or along heating-cooling panels applied to surfaces enclosing the space.

The forced air motion is affected by air delivered thru a diffuser outlet installed in the proper location on a wall, ceiling or at a mixing terminal. Air is brought to the diffusers thru ducts from an apparatus where it is cleaned and passed over heat exchangers within which circulate the primary heating or cooling media. Some induction terminals within the room have secondary coils that provide supplemental heating or cooling. Examples of primary and secondary cooling media are a direct expansion refrigerant, chilled water or brine. The heating media are usually steam, hot water, gas or electricity.

The temperature of the surfaces surrounding the occupant are subject to temperatures prevalent within and outside the structure. The surface temperature may be regulated by thermal panels applied to the ceiling, floor or walls. The secondary media circulated thru these panels is usually either hot or cold water.

To supply and circulate the media, there are available boiler and refrigeration plants complete with necessary auxiliaries and interconnecting piping.

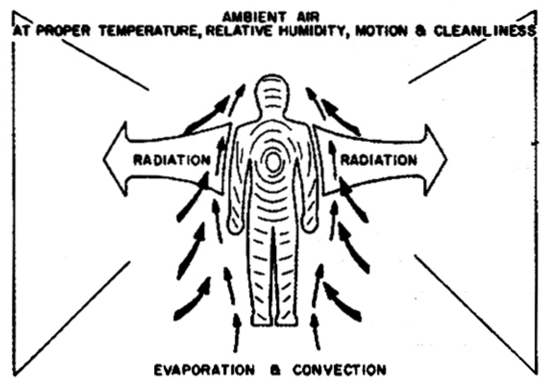


FIG. 2-HEAT DISSIPATION

SYSTEM COMPONENTS

The essential elements of an air conditioning system are illustrated in *Figure 1.*

The basic elements, optional components and their functions are listed in *Table 1.*

TYPES OF SYSTEMS

Air conditioning systems are generally divided into four basic types determined by the methods thru which the final within-the-space cooling and heating are attained. The air surrounding the occupant is the end medium which is conditioned; in some systems most of the themal effect is radiant.

The basic types are:

- Direct expansion (*Part 12*)
- All-water (*Part 12*)
- All-air (*Part 10*)
- Air-water (*Part 11*)
- Heat pump

TABLE 1-SYSTEM COMPONENTS

SYSTEM COMPONENTS	FUNCTIONS PERFORMED
Air Side	
1. Outdoor Air Intake (screen, louvers, dampers)	Path for outdoor air used for ventilation and marginal weather cooling
2. Preheater	Preheats air
3. Return Air Intake (dampers)	Path for return and/or recirculated air to apparatus
4. Filter	Removing contaminants from air
5. Dehumidifier (direct spray washer or cooling coils; DX, water, brine, with or without sprays)	Cooling and dehumidifying (air washing with sprays)
6. Heating Coil	Heating in winter and reheat for temperature and/or humidity control
7. Humidifier	Humidifying
8. Fan	Air propulsion
9. Duct System	Path for air transmission
10. Air Outlet	Air distribution within air conditioned space
11. Air Terminal (with outlet)	Enclosure for air handing; may be equipped with air mixing chamber, heating coil, heating and/or cooling coil, acoustic treatment, and outlet
Refrigerant Side	
12. Refrigeration machine (compressor, condenser, cooler and refrigerant piping)	Means for cooling
Water Side	
13. Pump	Water or brine propulsion
14. Water or Brine Piping	Path for transmission of water or brine between heat exchangers
15. Cooling Tower	Heat disposal from water used in condensing refrigerant
Heating Side	
16. Boiler and Auxiliaries	Provides steam or hot water
17. Piping	Path for transmission of steam or hot water

A self-contained compact unit located within or next to the air conditioned space and consisting of the minimum elements essential to producing the cooling effect is a direct refrigerant or *direct expansion (DX) system (Fig. 3)*. Heating may be either included with the unit or separate.

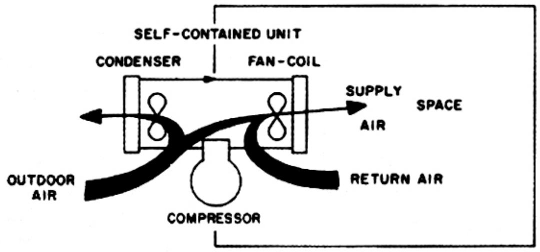


FIG. 3-DX SYSTEM

A cooling medium (chilled water or brine instead of direct refrigerant) may be supplied from a remote source and circulated thru coils of an air terminal unit within the conditioned space; the cooling medium is warm in winter to provide heating. A system of these terminal units is called an *all-water system (Fig. 4)*.

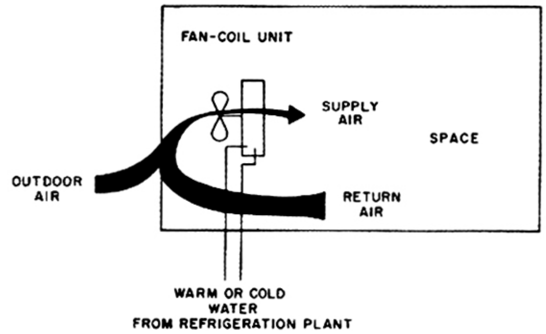


FIG. 4-ALL-WATER SYSTEM

Both the air treating and refrigeration plants may be located some distance from the conditioned space in a central station apparatus arrangement. Only the final cooling-heating medium (air) is brought into the conditioned space thru ducts and distributed within the space thru outlets or mixing terminal-outlets. Such a system is termed an *all-air system (Fig. 5)*.

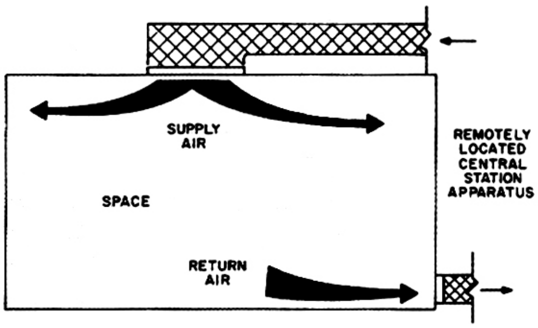


FIG. 5-ALL-AIR SYSTEM

The air apparatus and refrigeration plant are separate from the conditioned space; the cooling-heating of the conditioned space is affected in only a small part by air brought from the central apparatus. The major part of room thermal load is balanced by warm or cooled water circulated either thru a coil in an induction unit or thru a radiant panel. Such systems are termed *air-water systems (Fig. 6)*.

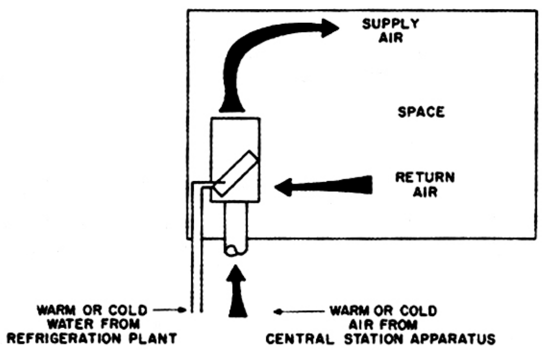
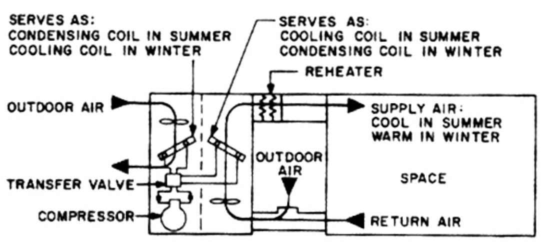


FIG. 6- - AIR WATER SYSTEM

An adaptation of any of the systems to effect year-round air conditioning utilizing system refrigeration as a heat generating plant is a *heat pump system (Fig. 7)*.



Note: Air to air version shown. Other versions are air to water, water to air, and water to water.

FIG. 7-HEAT PUMP SYSTEM

SYSTMES AND APPLICATIONS

This section discusses the specific components and characteristics of each system and variations within each system; it also indicates the major areas where these systems are applicable.

DIRECT EXPANSION SYSTEMS *(Part 12)*

A small direct expansion refrigerant self-contained *room cooling unit* is the simplest summer air conditioning system (*Fig. 8*). In one casing there are included the basic elements 1, 3, 4, 8, 10 and 12 (*Table 1*). With the addition of element 6 or adapting the unit to a heat pump arrangement, this self-contained unit is converted into a year-round system. A *large capacity self-contained assembly* may in addition incorporate elements 2 and 9 to serve a larger space. Control of the self-contained units is usually the on-off control of refrigeration equipment with step control in the larger sizes. The fan operates continuously in most cases.

The self-contained units are applicable to individual small or large rooms and segregated zones. Such spaces may be oriented to service an individual occupant or a group of occupants. These may exist in a private residence, office, commercial establishment or in a group of offices in a single zone.

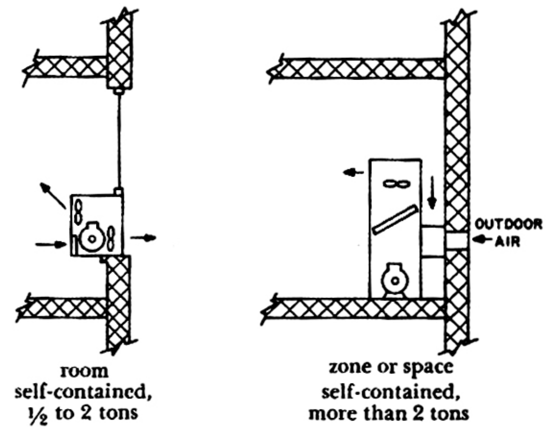


FIG. 8- DX REFRIGERANT SYSTEMS

ALL-WATER SYSTEMS *(Part 12)*

Maintaining the individual room air conditioning aspect while verging into the central station system of refrigeration is the all-water system of *room fan-coil units* (*Fig. 9*). Each unit within the system contains elements 1, 3, 4, 5, 8 and 10 (*Table 1*). Outdoor air is introduced thru the wall to each unit. The individual room self-contained refrigeration assemblies (element 12) are combined into one or more large capacity remote central source water chilling refrigeration plants with the addition of elements 13, 14 and 15. Room temperature is normally controlled by regulating a water valve at the coil within the room fan-coil unit.

The fan-coil unit all-water system with a central refrigeration and heating source can be converted to an air-water system by centralizing the primary air ventilation supply. This eliminates the individual unit thru-the-wall air intakes. They are combined into a central station air supply system. Air is delivered either to the fan-coil units or directly to the room thru a corridor duct system and separate outlets. The central ventilation air apparatus contains elements 1, 2 and 4 (6 and 7 optional). A return air system is not generally used. The ventilation air reheat coil assists in heating during marginal weather. During the true summer and winter weather the space cooling and heating respectively are provided by the fan-coil unit.

The room fan-coil unit systems are applicable in smaller multi-room buildings such as motor-hotels, factory office buildings and small medical centers.

The air-water system alternate is particularly adaptable where it is necessary to avoid undependable and architecturally unsightly thru-the-wall outdoor air intakes, but there is a need for defined and controlled ventilation as in office or apartment buildings.

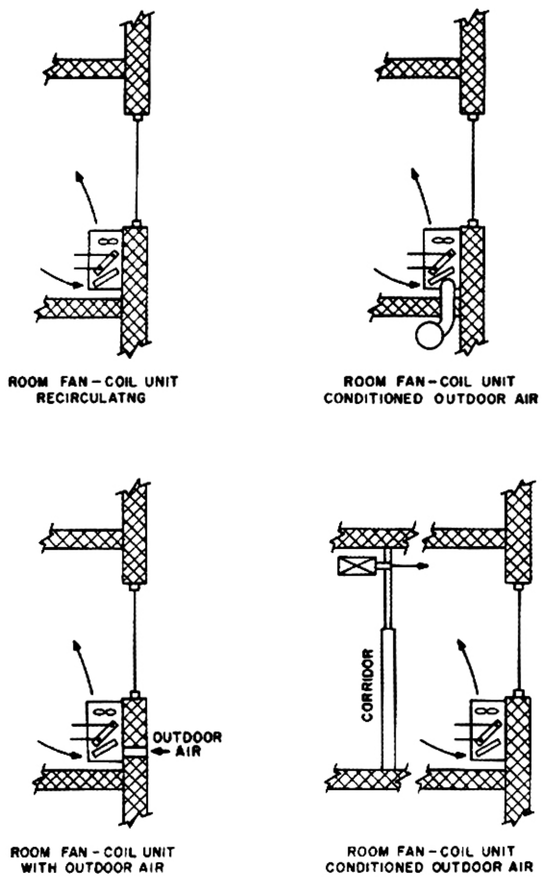


FIG. 9-ROOM FAN-COIL SYSTEMS

ALL-AIR SYSTEMS *(Part 10)*

Central station systems are examples of all-air systems. They may include all the elements from *Table 1*. The different systems are distinguished by their method of controlling the air supplied to the space

Volume Control

One way to compensate for a varying load is by regulating the volume of a constant temperature air supply (*Fig. 10*). When using standard side wall grilles or ceiling diffusers, the all-air *variable volume system* is limited to applications where the load varies less than 20%. Otherwise, if the air volume varies by more than 20%, the air motion within the space may be upset and create a drafty condition. But with an outlet that can maintain the space air motion regardless of volume reduction, volume control may be used more extensively. Then the *variable volume, constant temperature system* (*Part 10*) may be applied.

In the all-air *dual-conduit* system*, there are two streams of air. One is constant temperature and varies in volume to compensate for the fluctuating internal and sun load. The other is constant volume and varies in temperature during marginal or winter weather to compensate for the varying building transmission loss. This is an all-air system which parallels the high pressure air-water induction unit system discussed later in this text.

Bypass Control

Another method to compensate for a varying load is by reducing the amount of cooling air while maintaining the full quantity of supply air by including neutral air recirculated from the conditioned space.

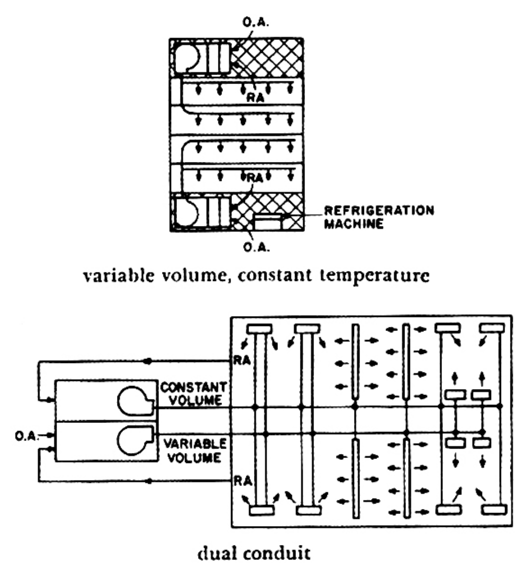


FIG. 10-ALL-AIR VOLUME CONTROL SYSTEM

*A Carrier patented system.

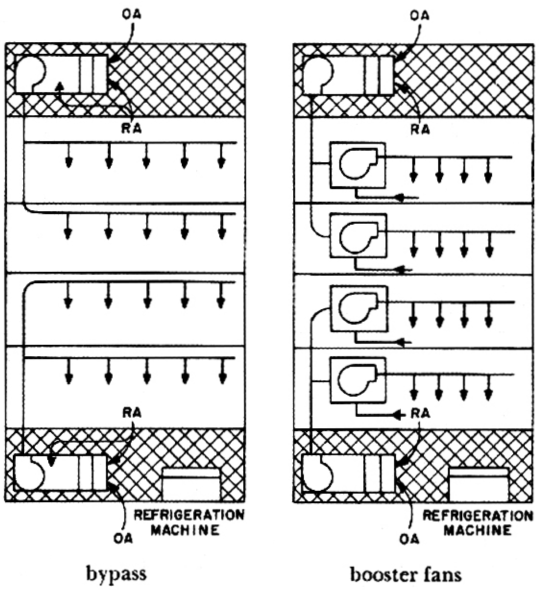


FIG. 11-ALL-AIR BYPASS SYSTEMS

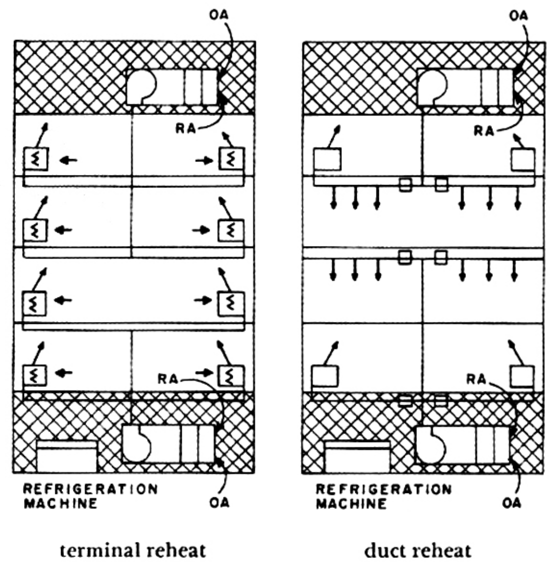


FIG. 12-ALL-AIR REHEAT SYSTEMS

This is the conventional face and bypass control system (*Fig. 11*), a variety of the *constant volume, variable temperature systems (Part 10).* The multizone system may be at times a bypass system. The air bypass may be remote from the conditioned space (at the central apparatus or unit) or within the room terminal unit (in the dual-duct system).

A system in which a single central station apparatus provides dehumidified air to a number of booster fans located on separate floors of a building (*Fig. 11*) or in separate zones is also classed as a bypass system.

The booster fans pick up the cooled air and pass it on mixed with recirculated (bypassed) air in needed proportions to compensate for a varying load. A fixed bypass is often used as a method of arbitrarily increasing the volume of supply air.

Reheat Control

The varying load may be compensated for by adding reheat either at the apparatus or within a terminal in the conditioned space, as with a *constant volume induction system*, or within overhead terminal-outlets (*Fig. 12*). The reheat at the apparatus may be supplied by a reheater either in a zone duct, within a multi-zone unit, or in the warm duct of a dual-duct system.

The *multi-zone blow-thru unit system (Fig. 13)* is a variation of the bypass and reheat system. Parallel heating and cooling coils provide an operation in which the cold air is mixed in needed proportions with recirculated air passing thru heating coils; the recirculated air is either unheated (bypass) or heated (reheat). The air mixtures proportioned by several pairs of dampers (located within the unit) are transmitted thru single ducts to individual zones. Thermostats located in these zones control the corresponding mixing dampers.

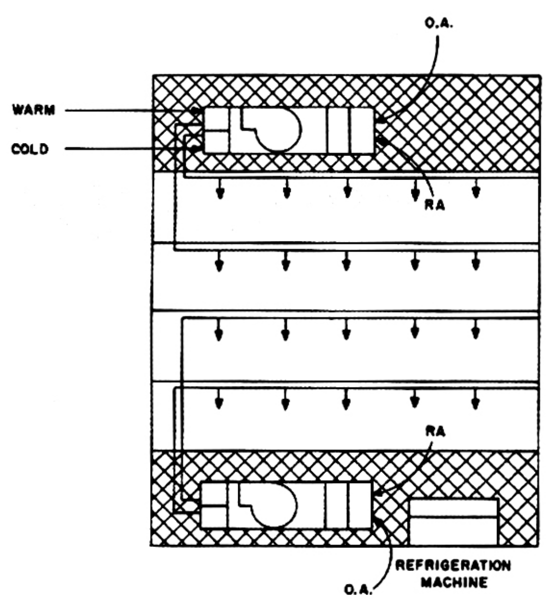


FIG. 13 – ALL-AIR MULTI-ZONE SYSTEM

The all-air *dual-duct system (Fig. 14)* supplies the mixing terminal units with air from two ducts, air streams at two temperature levels; one is cold, the other warm. The mixing terminal unit proportions the cold and warm air in response to a thermostat located in its respective space or zone.

The all-air systems ranging from the conventional bypass system thru the induction terminal reheat unit or zone reheat, multi-zone single duct, dual conduit and dual-duct systems have wide applications. These include the field of small single occupancy, single purpose building and multi-story buildings.

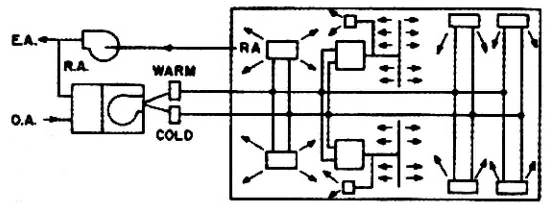


FIG. 14-ALL-AIR DUAL-DUCT SYSTEM

AIR-WATER SYSTEMS *(Part 11)*

The air-water systems are practical for reducing the floor areas occupied by the terminals, the cooling-heating media transmission system and the central apparatus. Most of the space load (internal and sun heat gains) is balanced by a water coil included in the room terminal. Small water pipes and small high velocity air conduits replace the bulky air ducts of conventional all-air systems.

The original air-water system is the high velocity high pressure *induction unit system (Fig. 15).* Primary air reduced to 20-25% of the conventional all-air system quantity serves to balance the building shell heat gains or losses, to satisfy the ventilation requirements, and to provide the humidity control and motive power to induce room air across the secondary cooling-heating coil within the terminal. The secondary coil produces year-round cooling or seasonal cooling and heating. In the latter case the primary air is cold year-round except during marginal weather when it is reheated according to a set schedule of temperatures.

The induction unit system is specially adaptable to load characteristics of the perimeter areas of multistory multi-room buildings. This system results in lower owning and operating costs.

A variant of the high velocity high pressure induction unit system is the *three-pipe induction unit system (Fig. 15).* Here the air stream (primary air) mentioned previously is not related to the structure shell transmission load; it is divorced from the heating of the building. It does provide the ventilation, humidity control and motive power for secondary air across the terminal coil. The three-pipe induction unit system is a year-round system that provides a simultaneous choice of either cooling or heating as required. One pipe supplies chilled water, the second pipe warm water, and the third pipe serves as a common return.

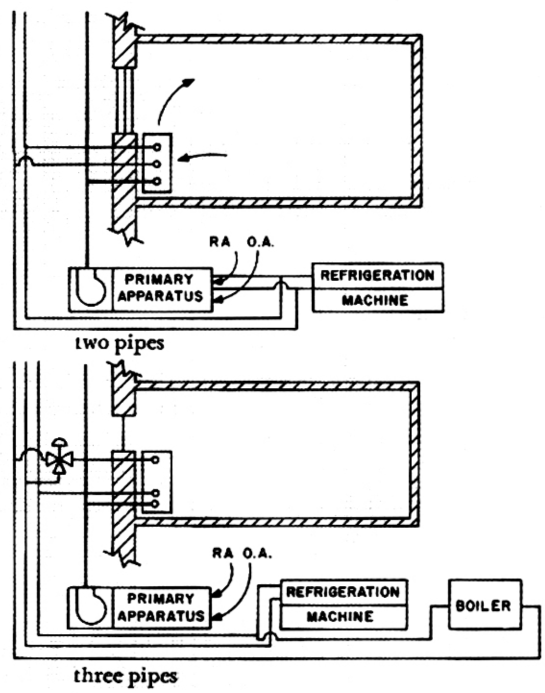


FIG. 15-AIR-WATER INDUCTION SYSTEMS

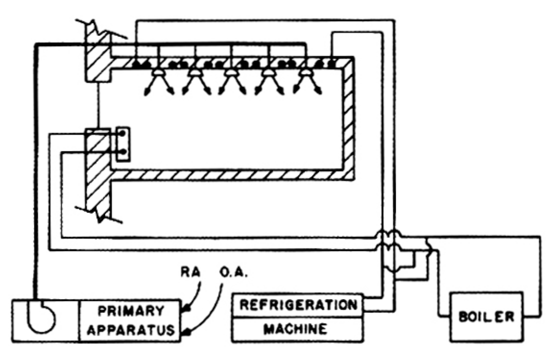


FIG. 16-AIR-WATER PANEL-AIR SYSTEM

The *panel-air system (Fig. 16)* is another variety of an air-water system. In this application the air quantity is similarly kept to an amount sufficient for ventilation and dehumidification requirements. The ceiling and wall panels have imbedded in or attached to them small pipe circuits thru which chilled or heated water is circulated. Panel-air systems may be applied with advantage to areas that have considerable gain of radiant energy from lights and sun. The exterior areas must be zoned separately from the interior since the latter usually presents a year-round cooling load.

System design and control arrangements are rather sensitive but the results are worth the effort because of more uniform ambient temperature conditions. However in areas of sharp load changes the inertia of the system may lead to temperature swings. It is claimed that the occupant has no objections to these temperature changes due to lower air motion. The reduced air quantity must be introduced into the space by means of an outlet that provides adequate induction of room air.

The air-water systems with high velocity, high pressure induction units, panel-air arrangements, and the all-water fan-coil unit system with centralized ventilation air ducted to units may be classed as primary air systems. The air quantity supplied in each case is at least the minimum ventilation requirement. The secondary air is introduced either by induction, unit fan or by thermal circulation in addition to induction.

HEAT PUMPS

A heat pump system is a refrigeration cycle which by design and control moves heat in either direction. Heat pumps are natural solutions of year-round air conditioning in buildings with a favorable balanced ratio of cooling-heating load, particularly where the two load values are almost equal. Heat pump systems are economical whenever the rates for electrical energy are advantageous against the costs of fossil fuels. It often pays to consider the attractive features of the heat pump system and analyze the over-all air conditioning project in the light of this system.

Any air conditioning system can be converted into a heat pump. It is a method of operation of the refrigeration plant that transforms a given air conditioning system into a self-contained year round system without the use of a separate boiler plant.

A heat pump system operation has the following advantages:

1. Over-all first cost saving - For many new buildings a single system can be installed to serve both cooling and heating. The cost of a boiler plant and auxiliary equipment including a smoke stack can be saved.
2. Space saving- Thru the elimination of boiler plant, smoke stack, fuel storage, etc.
3. Nuisance elimination – Does away with ash removal, smoke, soot and ash dust damage.
4. Single energy source – Electric power, simplifies accounting and service problems.
5. Increased safety – Thru elimination of handling of fossil fuels.
6. Fire insurance rate reduction – By elimination of fire hazards.

A refrigeration cycle can be applied to provide heating only, with future conversion to complete year-round air conditioning.

APPLICATIONS

The descriptions of individual applications that follow point out only the salient features that influence the air conditioning load calculations and selection of the most suitable system. The text is oriented mainly to summer air conditioning because many applications to existing buildings revolve around addition of summer cooling to the existing heating facility or its complete replacement by a year-round system. New buildings are assumed to incorporate year-round air conditioning at the inception of the project design. However even new buildings may include only the heating facility, with provision for future addition of cooling.

Any humanly conceived plan has room for improvement. The design engineer must apply his ingenuity in view of the wide variety of applications and idiosyncrasies within each application. Various technical publications contain articles and comprehensive texts on design guides and solutions for various applications. This text contains only the applications that have some characteristic prevalent to them. Other applications not discussed here either bear some resemblance to one of the described or are so individual that they have to be resolved by a separate unbiased analytical approach.

SINGLE-PURPOSE OCCUPANCIES

In this section are described system applications that are unidirectional, to serve either a home for a single human unit or a building serving an activity accommodating a large group of people. Thus one common temperature and humidity condition is to be maintained within a given space.

Residences

The architecture of residences is extremely varied, ranging from a standard repetitive package within large developments to an individual design for fashionable suburbia. Whatever the design there is a multitude of structural, orientation and shading devices by which the air conditioning load may be reduced. The complete appreciation and coordination of the data concerning the investor's aims, building structure, living habits of the occupant, and outdoor conditions should result in the most economical selection of equipment and its operating costs. Most important is the satisfaction of the owner and the occupant.

Residences represent the greatest single block of individual buildings. Of all the markets and applications of air conditioning, the residential market is the major one and is highly competitive. Special efforts are expended in defining the problem of air conditioning a residence (a 24-hour operation). At present there exists a unified industry-accepted method of load evaluation. Many manufacturers produce heating-air conditioning-heat pump equipment for residences. Dependability and ruggedness of equipment is their aim. Self-contained room units can be applied on an individual room basis in conjunction with the existing heating systems. Solar energy heating and air conditioning of residences may be considered.

Facilities for Dining and Wining

This classification covers restaurants, cafeterias, lunchrooms, lunchwagons, bars, cocktail lounges and night clubs. The outstanding characteristic of these applications is that the air conditioning load experiences sharp peaks at certain times of day and night. These peaks must be coordinated with the coincident outdoor conditions to arrive at a true cooling load. An absolute prerequisite is good ventilation with proper control of exhaust to neutralize odors of food and heavy smoking. This ventilation requirement is not only for the comfort of the occupant but also for preventing odor absorption by the walls and furnishings.

Another facet of load evaluation in this application is concentration of sensible and latent heat in dancing and entertainment areas.

Restaurants range from large dining spaces separated from kitchen and pantry areas to rooms adjoining the food preparing areas or where the cooking and pantry area is located in front of the service counters. In the later case extreme care should be taken in the exhaust-make-up system. Such a system should trap the heat gains and odors over the cooking area. There must always be an air movement away from the dining area.

Dining areas should be under positive pressure. Occasionally a certain amount of make-up air for kitchen exhausts may come from the dining area ventilation unless it is heavy with tobacco smoke. Kitchen and pantry areas should be under negative pressure. Whether the kitchen is to be air conditioned or ventilated, in either case all the heat and vapor producing equipment must be carefully scrutinized. The most offensive equipment should be equipped with efficient exhaust hoods to eliminate heat and moisture gains. Kitchen and pantry odors present a dual problem. The odors retained by various utensils, boards and other surfaces including the room itself may backfire by rendering otherwise fresh foods undesirable and unusable.

The size of the particular food dispensing establishment dictates the choice of an air conditioning system. The choice may also be directed by relation of the establishment to the over-all building complex if this happens to be either a tenant or an intrinsic part of the building. In some cases the same central station system serving the total building may be operated on a partial load basis during the weekend to serve only the restaurant. This can be done by recirculating at the apparatus the conditioned air assigned to the rest of the building. The building requirements of conditioned air are shut off while the restaurant continues to operate.

Variety and Specialty Shops

In this classification are shops and stores. These may be dress, shoe, fur, drug, candy or variety stores. The latter include sophisticated "five and ten" stores, supermarkets, or "country fair" type of small department stores. These are characterized by an 8-12 hour (at times 24 hour) operation cycle, varying population, high lighting intensity, and a considerable stock of goods or furnishings.

These areas call for special treatment of heat gains or losses and ventilation considerations: soda fountains; lunch and food counters; luncheonettes; pet sales; photo, candy, cigarette and food dispensers; open frozen food displays; beauty salons with their heat and odor producing equipment. There may be storage areas for candies, furs and other critical commodities that require special temperature and humidity conditions.

The stock and furnishings within a variety store can be utilized in load reduction by taking advantage of precooling effect. Cooling stored in the mass of stock to take care of peak loads helps to minimize the size of equipment. With high ceiling structures advantage may be taken of heat stratification using either natural venting or forced exhaust.

In most cases unitary self-contained equipment is applicable, either floor-mounted, ceiling-suspended or roof-mounted. At times the individual or combined projects may require either field-or factory –assembled fan-coil central stations with extensive ductwork. In conjunction with the air units larger refrigeration plants may be required, either direct expansion or water-chilling packages.

Bowling Alleys

The peculiar aspect of this application is that it is similar to spot or man air conditioning. Only the spaces occupied by bowlers, spectators and food dispensing are air conditioned. The alleys in front of the foul lines and the pin setting areas are not air conditioned. Because of high concentration of people (8 to 19 per alley) strenuous exercise and heavy smoking, ventilation must be generous and positive. The exhaust should be fan operated with the grilles located above the spectators and bowlers, beyond the foul line above the alleys. This prevents the spreading of tobacco smoke haze over the alleys. The room air returns should be numerous and at a distance from the food dispensing areas. Grilles, coffee urns and other equipment should be provided with exhaust hoods. The supply of conditioned air should be engineered to achieve draftless distribution. The equipment applicable is usually of the self-contained type; bypass and multi-zone units may also be used.

Radio and TV Studios

Radio and television studios vary considerably in size, occupying one or more floors of a building or a complete building devoted entirely to a network. Also there are small or large studios devoted to rebroadcasting. Large studios (especially color TV) have tremendous and variable loads of lights, cameras and equipment. Therefore, it is necessary to take full account of the loads and take all advantages to minimize these loads by utilizing every possible method of circumvention. The resulting air conditioning equipment and system should be economical and easy to control. The controls must be individual for each space, whether a studio, auditorium, control room, office or reception area. Electronic racks must have clean ventilating air and a direct exhaust; air necessary for this ventilation may come from surrounding studios, control rooms and office spaces.

Sound is an important element. Vibration and unwanted sound must be carefully controlled.

Individual applications dictate the choice of air conditioning system and equipment as long as the temperature and ventilation are satisfied without creating drafts or sound nuisance. With small installations multi-zone units are applicable.

Country Clubs

These oversize residences are usually located in open country, often on a hilltop completely open to climatic elements. The varying population is a problem, people often remaining late at night. The various activities and manner of occupancy dictates a careful analysis of individual room loads and overall refrigeration needs. The spaces range from social lounges, dining areas, cocktail lounges or bars to locker rooms and individual guest rooms. Some clubs have various recreational areas devoted to ping-pong tables, billiards and bowling.

This application suggests the use of any kind of equipment from room air conditioners to central station fan-coil assemblies serviced by water chilling refrigeration within the range of factory-assembled package equipment.

Funeral Homes

The problem of a large occupancy load for a short duration can be resolved economically by application of various expedients to reduce the load. The occupancy may also vary in size. The presence of flowers requires larger ventilation to dilute the odor effusion. A preparation room should have a good exhaust without any diffusion to the rest of the premises. Equipment selection is subject to the investor's capacity, method of operation and services provided. Quietness, ventilation ability and flexibility of control of capacity together with pre-cooling are the main attributes in the selection of a proper system.

Beauty Salons

Heat and odor emitting equipment (hair dryers, curlers, etc.) and compounds used are the special aspects of this application. An accurate evaluation of the actual load and arrangement for positive ventilation and exhaust are absolutely necessary. Both large beauty salons in individual buildings and small neighborhood shops fall into this category.

An additional problem exists in beauty salons located within department stores, hotels or other buildings. They must have negative pressure to prevent the spread of odors to adjoining areas.

Air distribution should be carefully designed to avoid drafts. There is no need for spot cooling.

Usually beauty salons present large areas with booths that have low partitions. There may be separate rooms for beauty treatments and massages. The air distribution in large areas is usually accomplished with ceiling diffusers, and the individual rooms are supplied by separate outlets.

The common single duct bypass or reheat system is adequate. Return air should incorporate an odor absorber to relieve the system of the requirement of an excessive outdoor air load.

Barber Shops

Air distribution that does not aim at a customer's neck or flow down mirrors should be a prerequisite. A proper ventilation rate should be chosen. Barber shops are often part of a large building unit; therefore they can be conditioned by the building system. Otherwise unitary self-contained equipment can satisfy the requirement.

Churches, Theaters and Auditoriums

These applications have one common feature, large population. A congregation of people may consist of a group quietly relaxed at prayer or an active crowd at a political rally. Judgment should be exercised in applying proper factors to provide sufficient capacity for varying latent and transmission heat gains. The load in ordinary cases may be standardized at 5 to 6 tons of refrigeration per one hundred people. However structures may vary from a large room or space as a part of a large building to cathedrals, opera and symphony halls, and large arenas. Often the cooling and heating air distribution cycles must be analyzed separately.

The major factors to ascertain for summer cooling loads are:

1. Pattern of patronage – One or many services in church, time of services or continuous; matinee and evening performances in theaters and auditoriums; nature of various sport or public events in arenas; coincidence of use of auditorium within a building with the operation of the rest of the building.
2. Ventilation – Possibly reduced to 5 cfm per person. Certain sport events and political rallies with heavy smoking require more ventilation.
3. Stratification – Application to loads, particularly in large structures.
4. Precooling – To reduce the size of air conditioning equipment, particularly refrigeration.
5. Climatic effects – Careful analysis of outdoor and solar design conditions coincident with peak patronage.
6. Inside design conditions – 77 F db and 60 percent rh quite acceptable.

The systems applicable to churches, theaters and auditoriums range from self-contained equipment to large field-assembled central station systems. Either water or ice refrigeration storage systems may be applied. Many of these structures may incorporate extensive auxiliary services for business, social and residential purposes. Use of these facilities should be an analyzed as to coincidence of loads with the major auditorium load. This analysis may help in the overall economics of system and equipment selection.

Dance and Roller Skating Pavilions

A large active population characterizes these applications. The sensible heat factor is quite low; therefore some sort of reheat must be added or more air handled to absorb the excess moisture. The active and spectator population must be considered. Inside design conditions should be coordinated with air movement around the active people. With higher air distribution velocities higher temperatures may be selected. Most of the factors pertaining to auditoriums are applicable. However ventilation requirements must be raised due to an excessive odor problem, 15-25 cfm per person (reduced to 10-15 cfm if activated carbon is used on the return air). Coincidence of lighting effects and activity must be analyzed. In roller skating rinks the winter heating requirements should be coordinated with the radiant effect of cold walls and rood. The cooling effect of the enclosure is not objectionable to skaters but may be unpleasant for spectators.

Systems applicable to these structures are judged primarily by the investor's attitude. Systems of self-contained equipment or central station fan-coil assemblies and refrigeration should be judged on a purely economic basis. The air distribution may be designed around a limited number of air diffusers or with extensive ductwork.

Factories

A distinction should be made between factory human comfort and industrial product air conditioning. The primary purpose of the former is comfort of the worker. In the latter case the ambient conditions of the product are of foremost concern. There are cases when the air conditioning is used for the benefit of both the worker and the product as in clean rooms or with precision products. The economics is the deciding factor, to have the worker efficient and satisfied resulting in a production of goods with minimum rejects.

The optimum indoor design conditions of temperature, humidity and air velocity are the keys to the efficiency of the worker. The indoor design conditions for nonfactory comfort application is established at 76 F and 45-50% relative humidity; this is the condition for efficient performance of light activity. Most factory workers can perform at 80-85 F with dewpoints at 55-70 F and ambient air velocities from 25-300 fpm. In a few instances workers may tolerate temperatures as high as 90 F. It must be remembered that it is the combined effect of temperature, humidity and air velocity ambient to worker location that influence the environment for factory worker efficiency. The ambient air velocity is the velocity sweeping the worker. The relative humidities may range from 35-80%.

If the design conditions and air movement for an entire project prove to be uneconomical, consideration should be given to individual cooling for a worker in a given spot or limited area.

In certain factories the mean radiant temperature may be significantly higher than the desired design dry-bulb temperature. Consequently it may be necessary to lower the design ambient air temperature and its dewpoint, at the same time increasing the air movement. If this solution cannot be achieved economically, shielding of the radiation should be considered.

To achieve minimum costs a careful analysis must be made of loads from lights, roof, walls, equipment, processes and workers to arrive at the actual operating load. The influence of these loads may be reduced by the application of diversity factors and principles of stratification and flotation of heat gains *(Part 1).* These two principles are aided by radiant heat exchange, natural tendency of heat to rise, exhausting of the warm air and an economic balance between the outdoor air taken thru the air conditioning equipment, the outdoor air introduced for heat flotation, and the exhausted air.

Spot or man cooling and standard compact single duct all-air systems are appropriate for applications in factory air conditioning. For widely scattered spot cooling stations it may prove more economical to convey chilled or evaporatively-cooled water thruout the factory instead of air. In such cases an air handling unit can be used directly as the supply air terminal or in conjunction with short duct runs.

MULTI-PURROSE OCCUPANCIES

Under this heading are described applications of air conditioning systems that are practical for large multi-room multi-story buildings or compounds of buildings. These are designed primarily for a single function common to all occupants, either work, residence, medical, or teaching and learning. Buildings are occupied by multitudes of people heterogeneous in their individual comfort desires; buildings vary in exposure to sun, wind and shading. This diversity requires dividing building into individual air conditioned zones. Zones range in size from large areas to a small room. Individual desires and a variety of coincident load conditions within a conglomerate of zones must be satisfied.

Multi-room multi-story buildings include offices and apartment buildings, hotels, motels, dormitories and hospitals. There are some basic problems common to all of these:

1. Simultaneous occupancy on all sides of a building with daily cycle of solar effects on east-south-west exposures.
2. Preference for individual control of space conditions under severe variations of load.
3. Necessity for sound and odor isolation of individual spaces.
4. Limitation in available space to house air conditioning equipment and pipes, conduits and ducts.

The following discussion outlines these basic problems in various types of buildings. It also points out the specific aspects that affect preference of one system or another.

Office Buildings

Office buildings are mostly multi-tenant; at times they may be occupied by a single tenant, a single organization. This aspect varies the approach to a solution of the problems. The multi-tenant building requires more exacting applications. Regardless of the occupancy most existing and some new buildings have the following basic areas to consider-the interior and the peripheral exterior areas. The interior areas are within the center of a building not influenced by outdoor elements, except the top story under a roof. Areas around the periphery of a building (exterior zone) may extend from 12 to 20 feet inward from the outside wall. This zone is exposed to sun, wind, outdoor temperature and shading of the structural elements or neighboring buildings. There is an evident need for two different air conditioning systems to handle the two areas marked by loads of different behavior.

An interior zone has a relatively constant load of lights and people. Therefore a single all-air system is the most applicable. However with complications of scattered addition of electronic equipment and provisions to switch off lights within a fully partitioned space, the system grows more complex. There may appear a need for either a terminal reheat, volume control, or dual-stream all-air system. Occasionally there may be an application for a primary air-secondary water system, particularly if the wattage is high.

Exterior zones have extensively varying load characteristics, from an extreme combination of sun gain thru glass, maximum outdoor heat transmission, lights and people to no load during marginal weather and to a maximum negative transmission load in winter. The exterior zone is also subject to moving shadows of building structural elements (overhangs, reveals, fins), neighboring buildings and clouds. These elements together with the desires of occupants require a very flexible air conditioning system. It must be capable of balancing loads which may change from cooling to heating or vice versa on different exposures and even in adjacent spaces on the same exposure.

Added to this is the requirement peculiar to a south exposure due to the fact that sun gain peaks in winter months when the sun is at a low altitude. Cooling may be required while the rest of the zones are on heating. The south zone MUST be given special treatment in selecting air conditioning terminals or even a separate system with a winter source of cooling.

Another peculiarity of a peripheral zone is the winter behavior of the building shell; it produces downdrafts along the outside walls. The latter also act as sponges for the radiant heat of occupants, making people quite uncomfortable unless compensated for by a higher ambient temperature.

Two additional characteristics of office or any multi-room, multi-story buildings are the fenestration and general architecture. These also influence the choice of air conditioning systems. The fenestration may vary from 25 to 75% of the outdoor wall area. In some buildings fenestration is eliminated. The buildings may be squat, may occupy large areas, and have a predominently interior zone. Buildings may be tall and narrow, consisting of only peripheral zones. Buildings with the same total areas devoted to air conditioning, one squat another tall, may have the refrigeration load vary only 5-10%, but there can be a large deviation in air handing equipment requirements.

To meet the widely fluctuating conditions of the exterior zones, the air conditioning system must have two fluids available for conditioned spaces, one warm or hot and one cold. The dual-stream all-air systems and primary air-secondary water systems can be applied to the exterior zones; the all-air systems require more space for apparatus and supply and return air ducts. Where the necessary space is available or can be sacrificed at the cost of some other gain, the all-air systems are appropriate. These systems are excellent from a ventilation point of view. They provide economy in refrigeration during marginal weather thru outdoor air cooling.

The primary air-secondary water systems are space savers. The primary air either takes care of the building shell transmission losses, minimum ventilation, dehumidification and provides motive power for the induction units, or it provides motive power for the induction units, or it provides ventilation and dehumidification only, as with three-pipe induction unit, panel-air or room fan-coil unit systems. Water carries the major burden of heat gain neutralization; space used by pipes is much smaller since water is over 200 times more efficient as a heat energy-carrying fluid than air.

Although office buildings are occupied mainly for 8-10 hour periods with some offices busy into the evenings, the air conditioning equipment should usually operate for at least 16 hours. During peak design conditions the air conditioning system should operate for 24 hours. This contributes to a more economical selection of equipment.

For some buildings the simplest and best system from a performance standpoint is the single duct all-air terminal reheat system. All the cooling is done with the supply air, and any variations in heat gain or loss are satisfied by a hot water, steam or electric reheat coil within the terminal unit.

It is necessary to repeat here the original premise expressed at the opening. There must be an appreciation of coincident elements of outdoor conditions, the building shell behavior and the inside conditions of load behavior. The result can be the proper solution of a given problem, subject to archited-engineer-owner-investor team cooperation.

There are some critical areas in each office building and these must be given special attention. Such spaces are conference rooms, special occupancies such as medical, laboratory, barber shops, beauty salons, restaurants, etc., or a concentration of electronic equipment or special rooms devoted solely to computer services. All of these are to be treated preferably as separate spaces to attend to their individual requirements of ventilation, odor and special thermal and sound problems. Keep equipment areas away from areas of high calibre occupancy and conference rooms since the best techniques in vibration elimination and sound attenuation may not completely satisfy the situation.

Hotels, Apartment Buildings, Dormitories

Much that has been said about office buildings and systems used can be applied to these buildings. However it must be observed that these buildings have mostly exterior zones. They are operated on a 24-hour basis thruout the year. Dormitories are an exception for the present but in the not-too-distant future they may also operate on a year-round basis.

Hotel guest rooms have a transient population, absent most of the day. Coincidentally the lighting load is also reduced. Considering these facts the individual room loads should be determined on the basis of exposure and either for early morning or late afternoon occupancy. The total refrigeration load should be based on the maximum load is either in the morning or in late afternoon with the corresponding occupancy, lights and sun effect; with predominant north-south exposures it is in the late afternoon with the corresponding occupancies, lights and sun effect.

Quick responding room temperature control and draftless, quiet air distribution are essential. Independent corridor ventilation is desirable. The toilet exhaust should approximate the room ventilation requirements. There should be independent systems for public spaces such as lobbies, restaurants, cocktail lounges or any services that a hotel may offer. All systems must be vibration- and sound-isolated from occupied areas. Practically any two-media system may be applied that confines air circulation to individual rooms. However this does not exclude the use of single-duct bypass systems in small hotels and where the local regulations permit the use of corridors as return air plenums.

Closely related to hotel applications are the modern multi-story motels that emerge from widely spread single-two-story motels. The application of various systems to the multi-story motels is similar to that for hotels. All-water 2- or 3-pipe room fan-coil systems or individual self-contained room units are more applicable to the single-two-story motels. In the latter case sometimes the direct use of outdoor air is excluded, relying instead on infiltration (natural or caused by toilet exhaust) for odor dilution. The excess infiltration should be estimated as part of the system load. The all-water system should be designed around a high temperature rise water circulation. Heat pump systems also are applicable.

Apartment houses and buildings range from 2-3 story garden type low-rise to high-rise multi-story complexes. Apartments range from multi-room luxury class to 2-3-4 room size to single room efficiency class. The occupancy of these apartments varies from fully filled during the day to an occupancy much like that of hotels, that is, occupied by professional people who are absent during most of the day. The occupancy diversity factor may vary from 75-80% down to 4-50%. The load calculations must recognize a 24-hour operation. In fact the 24-hour residential load estimate approach is applicable for arriving at the cooling-heating requirements.

Many systems may be applied to this application, depending on the size and configuration of buildings and the arrangement of apartments. These systems include individual self-contained units and heat pumps as well as all-air and air-water central systems. The investor and the size and type of project are prime factors in the selection of a particular system. Large apartment buildings often have auxiliary services such as restaurants, shops and office space rentals; these spaces should be handled by independent systems.

Residential hotels and apartment houses may have kitchen exhausts in addition to bathroom exhausts. This must be taken into account in balancing outdoor air intake with exhaust.

Modern dormitories are very similar to large size apartments; daytime occupancy may be taken at 50%. Building orientation and class schedules must be considered. There are no problems of kitchen exhaust; the interiors are rather austere. This means that the sound problem approaches that of an office building application.

Hospitals

The patient rooms of hospital buildings should be considered like hotels except that the load requirements are based on 100% occupancy with 24-hour, year-round operation. Depending on the predominant exposure the lighting load can be subjected to a diversity analysis. The important factor is that the air circulation must be contained within each room. Corridors, nurses stations and serving areas must have a separate supply. Each room must have an exhaust creating negative pressure. There should be no cross-communication (contamination) between various areas. The special treatment, therapeutic, maternity, surgical, morgue and other service areas usually have individual temperature, humidity and ventilation requirements.

Patient areas are best handled by primary air-secondary water induction systems. In a long building oriented east-west, with predominant north-south exposures, all-air reheat systems are applicable. The individual facility spaces are handled by independent self-contained or central station fan-coil assemblies. Absolute cleanliness from dust, odors and bacteria (along with rigid hospital housekeeping) is essential. This objective can be achieved easily with standard air conditioning systems and equipment. These must be simple to operate and particularly to maintain. Equipment that presents complexity soon loses proper attention.

Schools and Colleges

The need for year-round thermal environment in a schoolhouse is necessitated by concentrated school-room occupancy, elevated lighting intensity, suneffect in case of peripheral classrooms with windows and recognized improvement in performance of teacher-student instruction-absorption. Another element for the same need is the present tendency toward extension of the 9-month school year to a full 12 months. Even without the summer months the solution of cooling needs on the 9-month operation by use of ventilation is inadequate 25-90% of the time depending on location. Ventilation for odor dilution is an extremely important function. Depending on room cubage per pupil and student living habits the outdoor air requirement may vary 5-20 cfm per pupil. Thus the load due to outdoor air is significant.

The architecture of primary and secondary school building varies from one- or two-story standard arrangement single buildings to windowless highly utilized designs, to a compound of buildings devoted to individual functions. Whatever the arrangement the type of systems applicable to school air conditioning are extensive. Since the main prerequisite is introduction of sufficient outdoor air, all-air systems of any arrangement are the best choice. They operate economically by using outdoor air cooling any time the outdoor temperature drops below 60 F. The package equipment and all-water room fan-coil units have limited applications. The air-water system has extremely limited use.

The previous text has been oriented essentially toward primary and secondary schools. Institutions of higher learning, colleges, institutes and universities, present similar problems which extend to a larger variety of occupancies. The buildings are often multi-story structures for single and multi-purpose occupancies; therefore the system selection has greater latitude. The refrigeration needs are often supplied by a central plant paralleling the arrangement of central heating.

Department Stores

The more extensive the department store, the more attention must be paid to problems of each floor or to departments within a particular floor. The nature of each floor is very individual. On the other hand a department store may be quite uniform in singularity of purpose and therefore may be handled as a unit.

Care should be exercised in evaluating the population and local shopping habits. The location of a department store is critical: serving a large city (purely urban population) or a small town (catering to farming communities); as part of a shopping center or in a deluxe setting. The patronage pattern is individual in each case.

The air cycle of a department store air conditioning system should correspond to the load of the specific area or floor or at times the whole store. However the refrigeration plant is sized on the basis of a net instantaneous load taking into account the population diversity factor of the entire store. Full advantage should be taken of outdoor air for cooling during the winter. Outdoor air preheaters should be designed to temper the maximum outdoor air quantity.

A variety of air conditioning systems may be applied to department stores; self-contained units or multiple central station fan-coil assemblies with minimum ductwork may be used. A main dehumidifier central station apparatus may supply chilled air to recirculating booster fans in various areas or floors. One central station assembly with extensive ductwork may serve a department store as a unit. Individual conditions can be maintained in a manner suitable to the circumstances. It may be either a total apparatus bypass control or an individual area volume control.

Shopping Centers

The trend toward concentration of shops, variety and department stores in outlying areas has led to the development of shopping centers. Problems of load calculations are stated under individual categories. However the design of air conditioning systems is dominated by the economics of investment and service to the operators of stores or by agreement between the lessees and lessor. The major choice is either individual self-sustaining treatment of each store unit or a central refrigeration along with a boiler plant. In the latter case the cooling and heating services are distributed to each on an equitable basis. Stores are usually equipped with individual air cycles as part of the unit design.

An additional feature of shopping centers is a covered mall connecting the stores and plazas between the stores. These mall areas are usually air conditioned at somewhat higher temperatures than the surrounding stores. Doors from stores to the malls usually stay open. Ventilation air from the stores is usually exhausted thru the malls. At times there are openings above small central plazas within a store compound; these opening serve as exhaust relief.

Libraries and Museums

This application belongs to the industrial type since it is primarily for the benefit of various products. The products are on permanent display; although the design conditions are strict, this application is similar to one for human comfort.

Libraries and museums housing collections of books, fine and technical arts, historical and natural sciences are often located in large cities. This location exposes the collections to a polluted, destructive atmosphere. Air conditioning with special attention to filtration and elimination of atmospheric pollutants *must maintain year-round constant temperature and humidity*. Fortunately the indoor design conditions are within the human comfort range. A thorough air movement must be established to avoid stagnant corners.

The control of space relative humidity and the object humidity, that is, the humidity of the thin film in close contact with the object surface, is very essential. The space relative humidity affects the equilibrium of moisture content between the object and the ambient atmosphere. The object humidity affects the surface of the object. In both cases excessive moisture acts as a destructive agent.

The equipment for conditioning the air may be any kind within the economics of the given project. In contaminated areas considerations should be given to the removal of acidic fumes and vapors by employing direct spray dehumidifiers or sprayed coils with spray alkalinity maintained at a pH value of 8.5 to 9.0.

The ideal system is one that is well zoned with central dehumidifying equipment and booster fan stations using bypass or steam, hot water or electric reheat control. In all cases the automatic control should incorporate a safety device to prevent over-humidification. Equipment vibration isolation and acoustic attenuation must be part of the design. The system must operate 24 hours year-round.

Laboratories

The use of air conditioning systems in laboratories provides one or more of the following services:

1. Control of regain in hygroscopic materials.
2. Influence of physiological reactions (comfort).
3. Control of chemical reactions.
4. Control of biological reactions.

With regard to their functions laboratories can be grouped in the following types:

1. Research
2. Development
3. Test
4. Calibration
5. Pilot plants

Individual laboratories (singly or collectively) are usually designed for a specific condition or for a range of conditions of temperature, humidity and cleanliness (white or clean rooms). These functions must be maintained to very exacting requirements. The controls and safeguards must often be quite elaborate.

The discussion that follows is confined to laboratory buildings, where modules, research personnel offices and conference rooms, libraries and work shops are combined under one roof. Chemical research laboratories are equipped with exhaust hoods that present specific problems.

In the design of air conditioning systems for laboratory buildings the application of standard design patterns and practices is very limited. Each laboratory and building is a problem in itself that requires the following considerations:

1. Exact room conditions.
2. Specific ventilation, often oriented to the exhaust requirements.
3. Separation of general occupancy spaces.
4. Orientation of heavy load laboratories away from the additional burden of sun gain.
5. High load variation in each laboratory
6. Diversity in use of laboratories.
7. Diversity in loads thruout the building.
8. 24-hour operation of laboratory spaces.
9. Constant or variable exhausts.
10. Concentrations of sensible or latent heat, requiring either special exhausts or spot cooling or both.
11. Corrosive effects of fumes on parts of the air conditioning, ventilation and exhaust systems.
12. Explosion hazards.

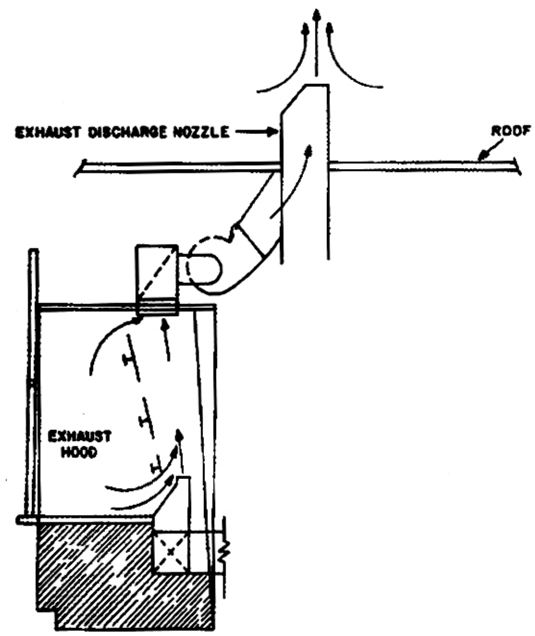


FIG. 17- INDUCTION HOOD

The load calculations are made in accordance with *Part 1*, taking account of any special heat gains and customer specification of indoor design conditions. The recommended ventilation is 15-20 cfm per person unless the amount of exhaust demands larger quantities.

The selection of an air conditioning system is dictated by the grouping of similar spaces (zoning) and individual requirements of separate spaces. The ordinary comfort applications are open to any type of system; the variable load spaces are best treated with multi-zone reheat systems such as a constant volume, variable temperature system; the spaces with concentrated and special loads may need spot treatment of either temperature, humidity and/or cleanliness provisions. Standard equipment is applicable except for explosion hazards and corrosive fumes requirements where applicable.

Fume exhausts may present unusual problems of both functional and economic nature. The conditioned make-up air necessary to fill the exhaust air requirements is a major burden on the system and increases costs. The intermittent and varying use of exhaust hoods presents a difficult air balancing problem, with special attention to selecting proper air handling equipment. One solution of fume exhaust is the application of self-ventilated hoods (*Fig. 17*); the exhaust hood requirements are divorced form the air conditioning system. Untreated outdoor air (heated in winter) is introduced directly to the hood and exhausted either from a group of hoods or individually. The latter method is followed when there is a danger of mixing exhausts because of an explosive or corrosive nature.

In this connection it is necessary to discharge the exhausts forcibly upward in order to fully diffuse the fumes to protect possible recirculation into the outdoor air intakes, whether for ventilating the exhaust hoods or the air conditioned spaces.

Marine

The air conditioning of ships, whether a luxury passenger liner or a cargo vessel, follows the patterns on land. However, in defining the outdoor design conditions it is necessary to determine the zone of sailing coverage. Normally it is recommended that the summer outdoor design conditions are 95 F db and 82 F wb unless sailing areas are predominately tropical. Then the average warm port of call defines the summer outdoor design condition. The coldest port of call pinpoints the winter outdoor design condition. Indoor design conditions are similar to applications on land. The sun effect thru glass must be evaluated on a maximum basis because of no definite orientation. there is an added factor of sun radiant energy diffusely reflected from the water surface. Ventilation needs aboard ship are larger due to the limited volume of quarters and general malodors specific to ships. A minimum of 12.5 cfm per person or 2.5 air changes per hour, whichever is greater, should be used to estimate ventilation. Deluxe passenger vessels should have more ventilation.

The compactness of the hull of a ship completely utilizing each cubic foot of space leads to specific considerations in the selection and design of air conditioning systems and equipment. Generally systems for staterooms and crew quarters are limited to air-water induction, all-air reheat and dual-duct systems. The public spaces are air conditioned by field-or factory-assembled conventional all-air central station fan-coil systems.

The equipment installed aboard ship should be selected to satisfy the following requirements: a minimum of space; minimum noise and vibration; operation under conditions of ship's roll and pitch; use of materials able to withstand the corrosive effects of sea air and salt water; and sufficiently maintenance-free for the duration of a voyage. To be prepared for emergencies the systems should be adequately supplied with spare parts and maintenance materials.

Table 2 presents a summary of the various applications and air conditioning systems.

TABLE 2-SYSTEMS AND APPLICATIONS

	APPLICATIONS		Individual Room or Zone Unit Systems				Central Station Apparatus Systems						
			DX Self-Contained		All-Water		All-Air					Air-Water	
			Room	Zone	Room Fan-coil		Single Air Stream					Prim. Air Systems	
									Reheat		Multi-Zone		
			1/3 to 2 tons	2 tons and over	Recir. Air	With Outdoor Air	Variable Volume	Bypass	At Terminal	Zone in Duct	Single Duct	Secndry. Water H-V H-P Induction	Room Fan-Coil with O.A.
		Page	(9-8)	(9-8)	(9-8)	(9-8)	(9-9)	(9-9)	(9-10)	(9-10)	(9-10)	(9-11)	(9-8)
Single-Purpose Occupancies	Residential Medium	(9-13)	x										
	Residential Large			x	x						x		
	Restaurants Medium	(9-13)		x						x			
	Restaurants Large			x				x	x	x	x		
	Variety & Spctly. Shops	(9-13)		x									
	Bowling Alleys	(9-14)		x				x					
	Radio and TV Studios Small	(9-14)		x				x		x	x		
	Radio and TV Studios Large			x				x		x	x		
	Country Clubs	(9-14)		x				x		x	x		
	Funeral Homes	(9-14)		x							x		
	Beauty Salons	(9-14)	x	x									
	Barber Shops	(9-15)	x	x									
	Churches	(9-15)		x				x			x		
	Theaters	(9-15)						x					
	Auditoriums	(9-15)						x					
	Dance and Roller Skating Pavilions	(9-15)		x			x	x					
	Factories (comfort)	(9-15)		x				x		x			
Multi-Purpose Occupancies	Office Buildings	(9-16)					x				x	x	
	Hotels, Dormitories	(9-18)			x	x						x	x
	Motels	(9-18)			x								
	Apartment Buildings	(9-18)				x						x	x
	Hospitals	(9-18)				x				x		x	
	Schools and Colleges	(9-19)				x	x	x	x	x			
	Museums	(9-20)								x	x		
	Libraries Standard	(9-20)		x				x		x	x		
	Libraries Rare Books			x						x			
	Department Stores	(9-19)						x					
	Shopping Centers	(9-19)		x				x			x		
	Laboratories Small			x			x			x	x		
	Laboratories Lge Bldg	(9-20)					x		x			x	
	Marine	(9-21)							x			x	

NOTE:
1. Systems checked for a particular application are the systems most commonly used. Economics and design objectives dictate the choice and deviations of systems listed above, other systems as listed in Note 2, and some entirely new systems.
2. There are several systems used on many of these applications when higher quality air conditioning is desired (often at higher expense). They are Dual-Duct (9-11), Dual Conduit (9-9), 3-pipe Induction and Fan-Coil (9-11), 4-pipe Induction and Fan-Coil, and Panel-Air (-12).
3. Numbers in parentheses are page numbers of the text describing the particular system or application.

INDEX

PART 9 WATER AND DX SYSTEMS

FIGURE PART 9 WATER AND DX SYSTEMS